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In-House Report
July 1977

TEST AND EVALUATION OF US ARMY RESTRAINT PANEL (BROOKS AND PERKINS MECHANICAL RESTRAINT SYSTEM B)

John Guba
Douglas J. Holzhauer

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Air Force Systems Command
Griffiss Air Force Base, New York 13441

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This report presents the results of static and dynamic deflection testing of the Type "B" (Brooks & Perkins) Mechanical Dunnage System Kit, designed to structurally upgrade commercial 20 foot International Standard Organization Containers (ISO) for transportation of hazardous material (ammunition) in International Commerce.

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I INTRODUCTION

Background: The test and evaluation of an Ammunition Restraint Panel was conducted by Rome Air Development Center (RADC), Griffiss Air Force Base, for the Department of the Army, US Army Mobility Equipment Research and Development Command (USAMERADCOM), Fort Belvoir VA, as part of its Research and Development (R&D) Program for developing Ammunition Restraint Kits for Commercial Cargo Containers. USAMERADCOM is assigned the R&D mission to upgrade the structural capacity of these containers to transport military explosives in international commerce. By law, safety is the overriding consideration in munition traffic management. The International Standardization Organization (ISO) Cargo Container is an internationally accepted modular structure which is cost effective to transport, stuff and strip of its cargo, and it reduces pilferage and damage. It lends itself specifically to the principle of inventory in motion. By 1978, about one half of the US Merchant Fleet will be cargo container vessels and military forces will be captive of this transportation system.

The 20 foot Milvan is the primary container used in the containerized Ammunition Distribution System today. Because ISO containers have less structural capacity than the Milvan, the Association of American Railroads (AAR) has not approved their use for surface movement of explosives in the continental United States, and the US Coast Guard will not permit port handling and ocean movement. To overcome this problem, USAMERADCOM developed a quick installation Ammunition Restraint Kit to work in steel, aluminum and Fiber Glass Reinforced Plywood (FRP) ISO containers.

Objective: The objective of the RADC effort was to prove, through static and dynamic testing, the ability of the restraint kit panel to meet the test requirements of the Bureau of Explosives, AAR, and the US Coast Guard.

Panel Construction: The panel is 230.5" long, 86.75" high and 2" thick, constructed of 6061-T6 aluminum, preformed into a corrugated structure. It is reinforced on one side by belt rail members and with tension strips on the other side, which are spot welded to the panel corrugation. Extruded members sorround the panel corrugation and are fastened by rivets. The corners of the panels have special bolts which secure the panel to the corner posts of the cargo container. The bolt assemblies are tightened against the container corner fittings and tack welded. The top and bottom of the panel are fastened to the cargo container walls with Huck bolts at the extruded frame.

Testing: The following tests were conducted:

1. Three static tests, where loads of various magnitude and configuration were placed on the restraint panel.

2. A fatigue test, with cyclic loadings that simulated a Sea State 10 Condition in duration and period (the loading conditions and magnitude were the same as static test No. 3).

In all tests the simulated loads were derived from the outloading diagrams for Milvans.

Deflection patterns were developed from these loadings. Deflection was measured over the total length of the panel at three locations; two equally spaced from the centerline and one on center. The amount of deflection was measured with a Starrett Dial Indicator measuring to .001 inch with a total travel of three inches.

STRESS COAT and strain gages were used to locate maximum stress locations under dynamic loading conditions. Strain gages were attached on the surface of the panel, where the cracks in the STRESS COAT indicated a high stress condition. A loading cycle was introduced to approximate the ship roll condition at Sea State 10.

II EQUIPMENT DESCRIPTION

A. Test Fixture: The test fixture is a rectangular shape framework which contained the test specimen and the hydraulic cylinders. As shown in Figure 1 of this report, the rigidity of the framework assures that the measured deflections are due solely to the panel deforming.

B. Hydraulic System: A hydraulic system was selected as the optimum force producing mechanism to induce a variety of load patterns into the panel. Variations in pressure, the ability to automate the cyclic loadings, and the ability to reproduce the different loading patterns were the basis for its selection.

The hydraulic system consists of an axial piston pump, manifold valves, and 40 single acting cylinders. The system is designed to operate at a maximum working pressure of 3,000 PSI. The pump (Figure 2) is a variable flow pressure compensated model which can produce a 106 PSI uniform loading on the test panel with the 40 cylinders. It has a 10 gallon/minute maximum flow rate which will raise the cylinders to maximum height (3.0 inches) in 10 seconds. The supply and return flow rates can be adjusted individually. The manifold system was fabricated using schedule 80 steel pipe and fittings. It was designed to have a minimal flow resistance to the fluid, to assure that the panel could be unloaded rapidly. At 3,000 PSI pressure, each of the cylinders can produce a maximum force of 53,000 pounds. The elasticity of the test panel returned the pistons to their initial position. The cylinders can be moved on the supporting "I" Beam to apply loads at different points on the panel.

The force produced by the cylinder is distributed into the panel through a 4-point load spreader (Figures 3 & 4). Thus, the forces can be distributed linearly or uniformly as needed. The linear load is produced by using two

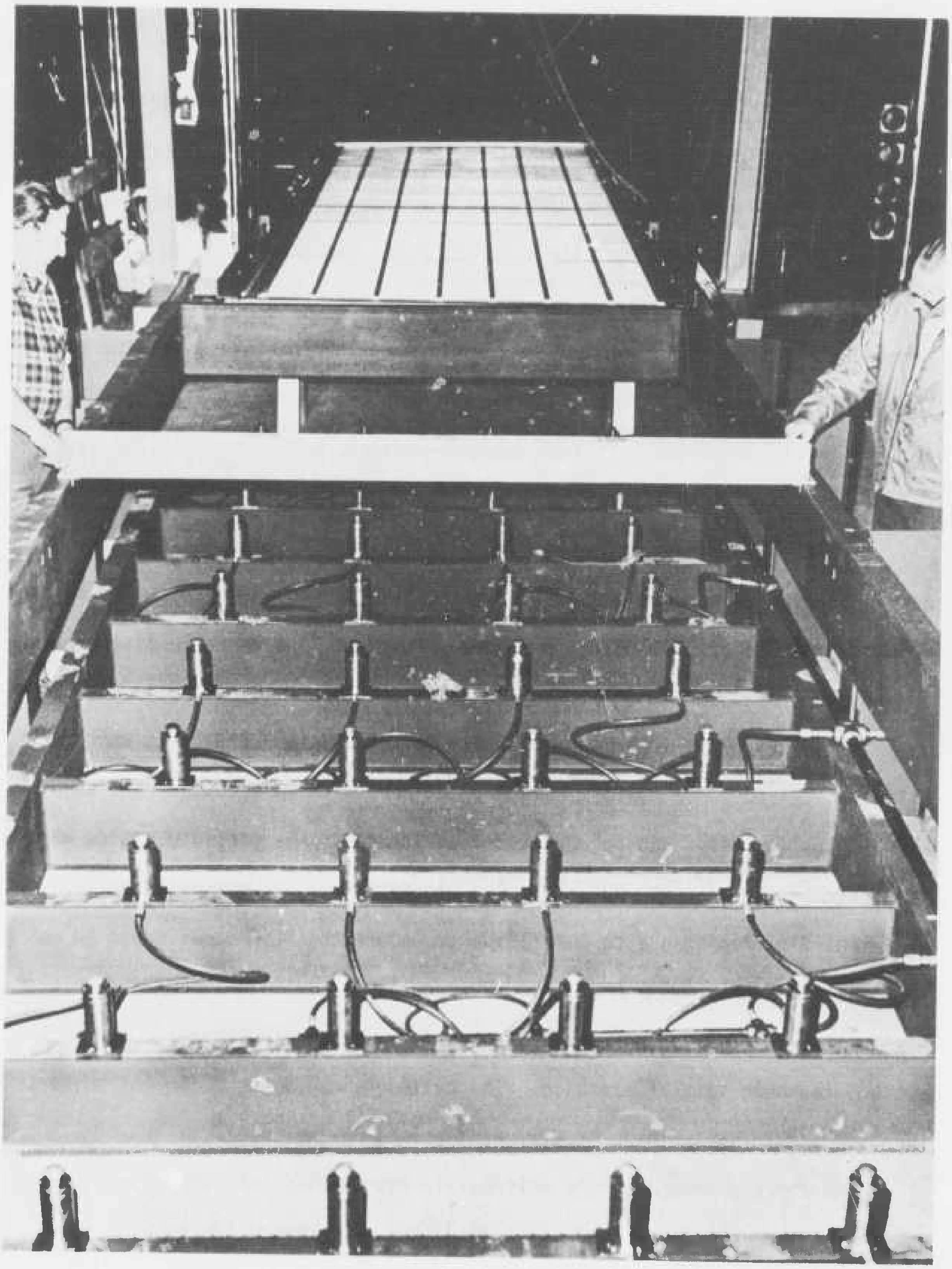


FIGURE 1 FRAME, MANIFOLD AND CYLINDERS

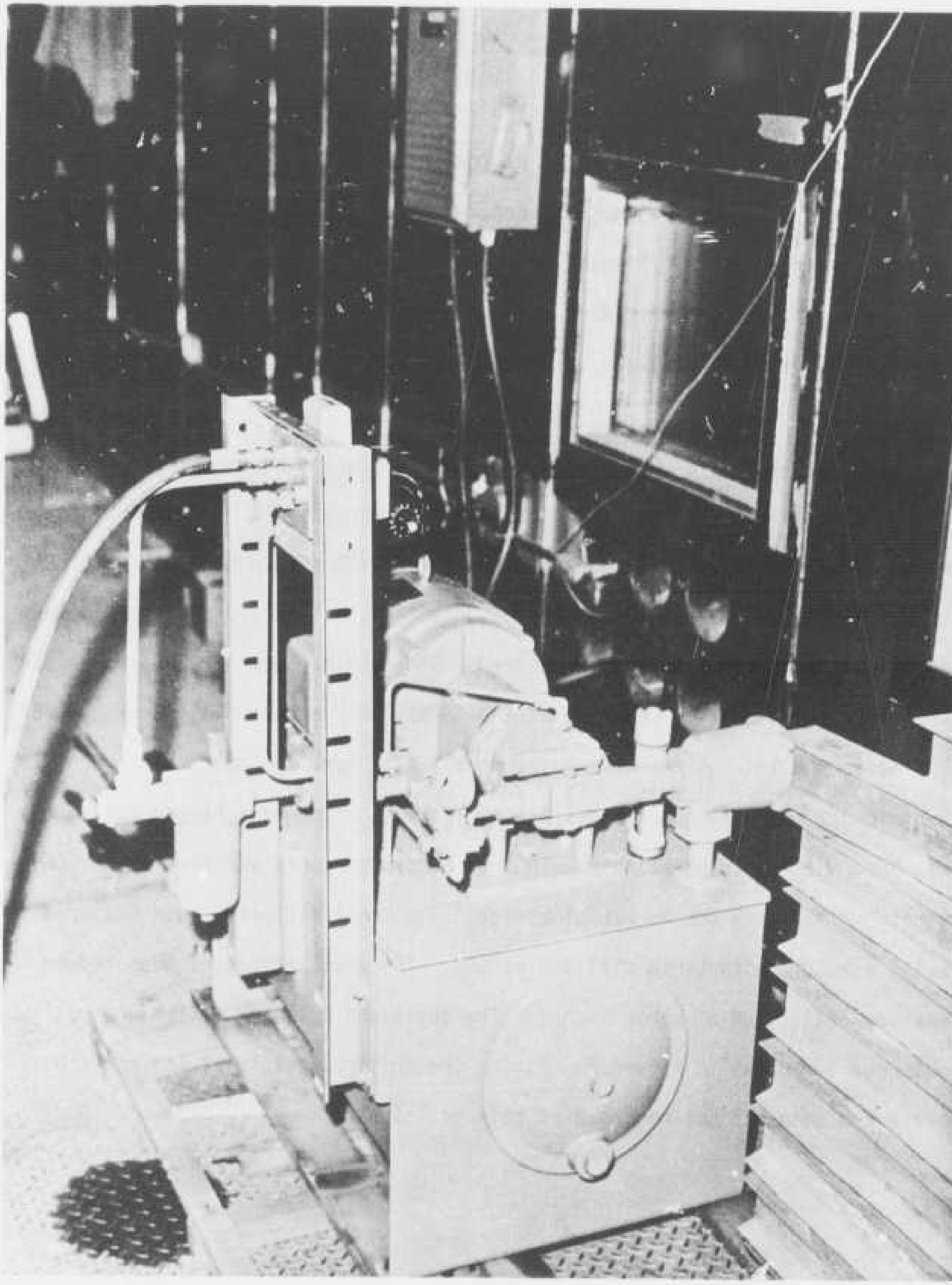


FIGURE 2 HYDRAULIC PUMP

pads, one placed at each end of the adjoining beam of the load spreader. The uniform load uses four pads placed at the corners of the spreader arms.

The hydraulic system uses two separate flow control valves to adjust the supply and return rate. A solid state time delay was used to vary the load cycle and the number of cycles was recorded by an electronic counter. (See Figure 5). The line pressure was set using a 0-3,000 PSI hydraulic gage at the manifold branch line. Its accuracy is .5 percent.

C. Measurement of Deflection and Strain: During both static and dynamic tests, the skin strain was measured using strain gages and measurement instrumentation. To locate the placement position of the strain gages, STRESS COAT was used. The STRESS COAT was sprayed onto the panel before each static test and a static load was gradually applied. The strain gages were placed at the positions where initial cracking of the STRESS COAT occurred. (See Figure 6). The maximum strain points were assumed to be the same for both static and dynamic load condition. A BAM-1 direct reading strain measurement instrument was used with a strip recorder. Thus an accurate record was kept of how panel strain varied with the number of cycles. The panel deflection was measured using a bridge with three dial indicators. The dial indicators measured a maximum deflection of three inches. The positions at which deflection was measured are shown in Figure 7. During the initial test, dial indicator No. 3 broke and data was not recorded at this position.

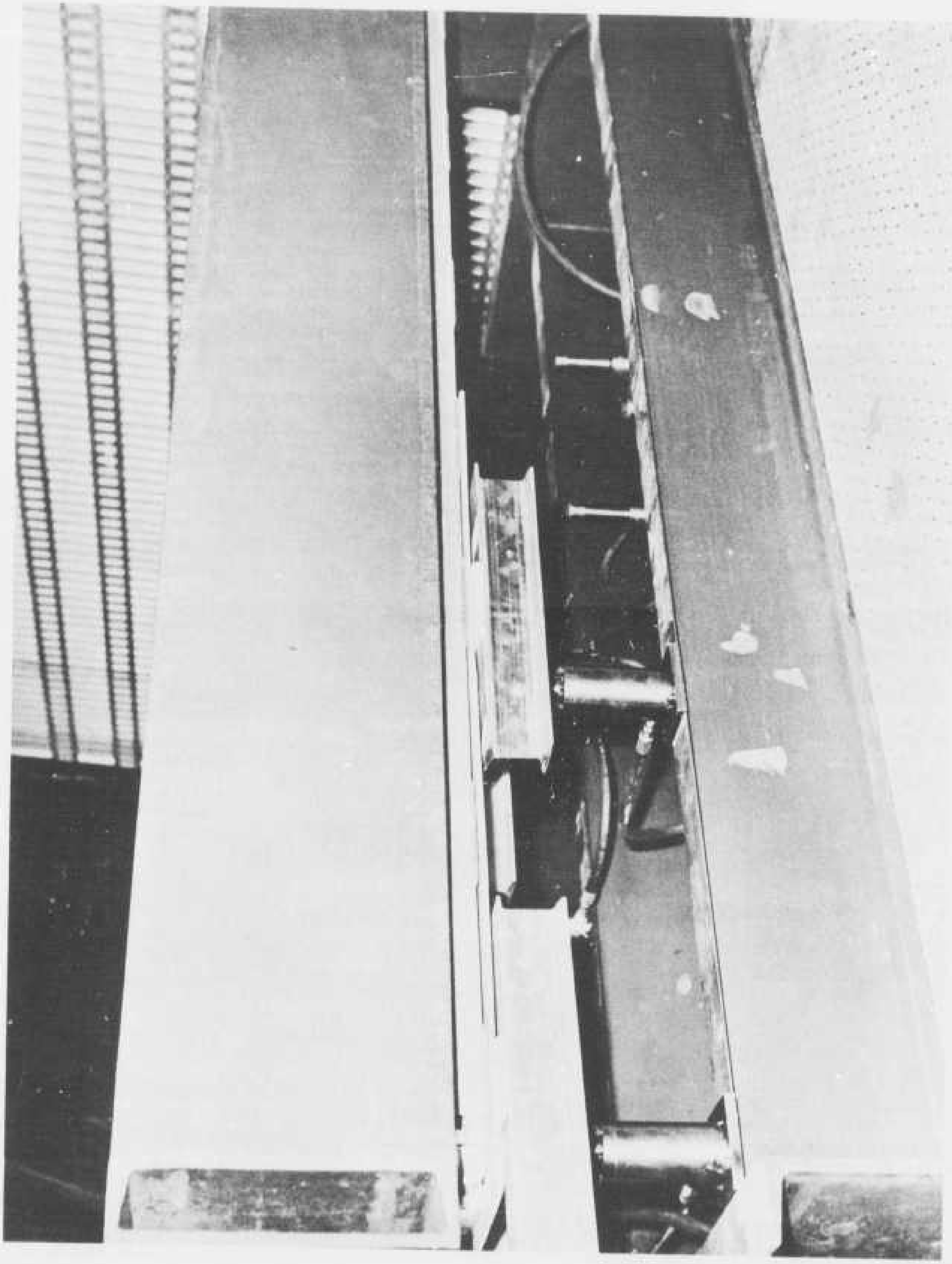


FIGURE 3 ARMY RESTRAINT PANEL TEST

FIGURE 4 LOAD SPREADER ON CYLINDER

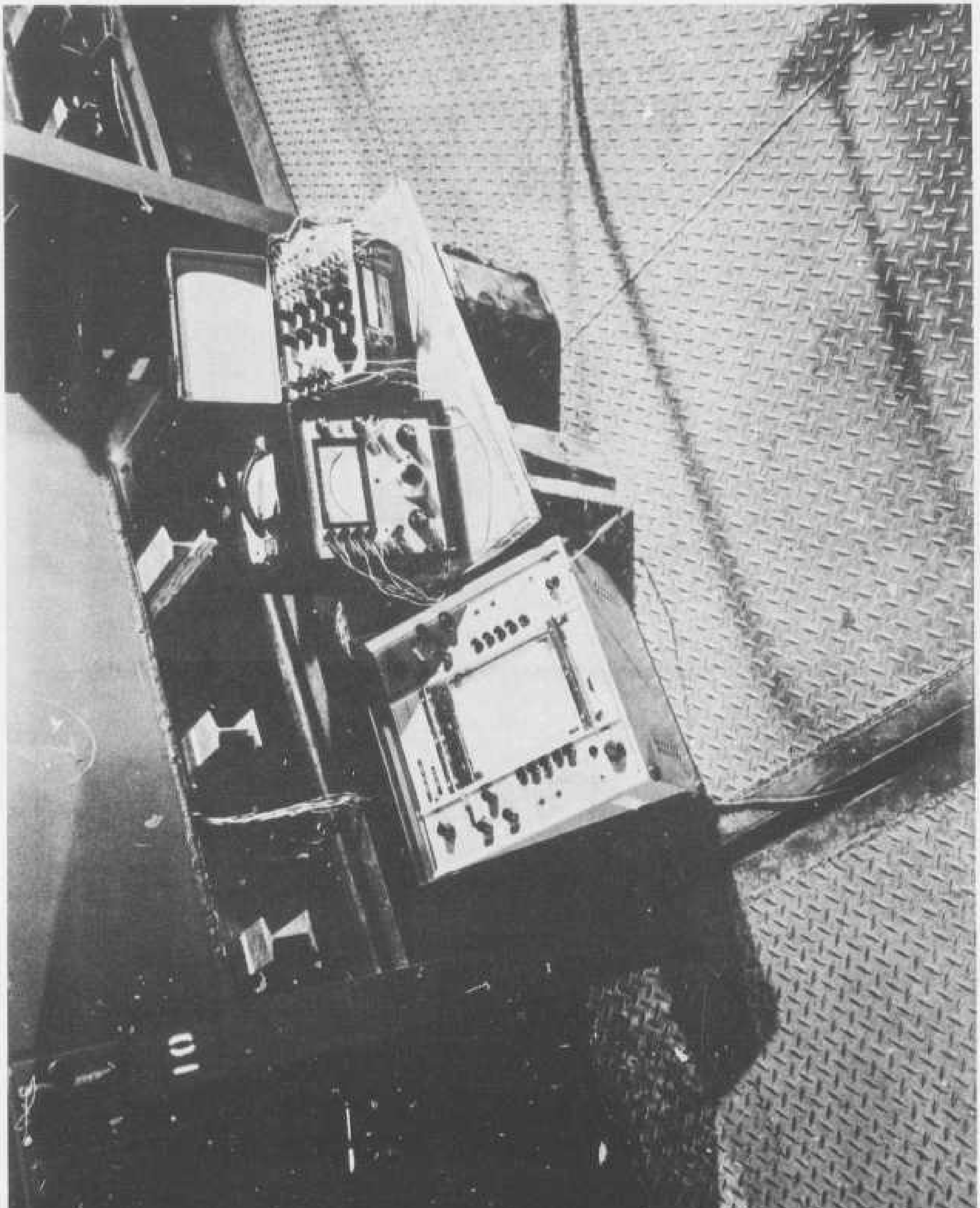


FIGURE 5 STRAIN GAGE INSTRUMENTATION AND RECORDER

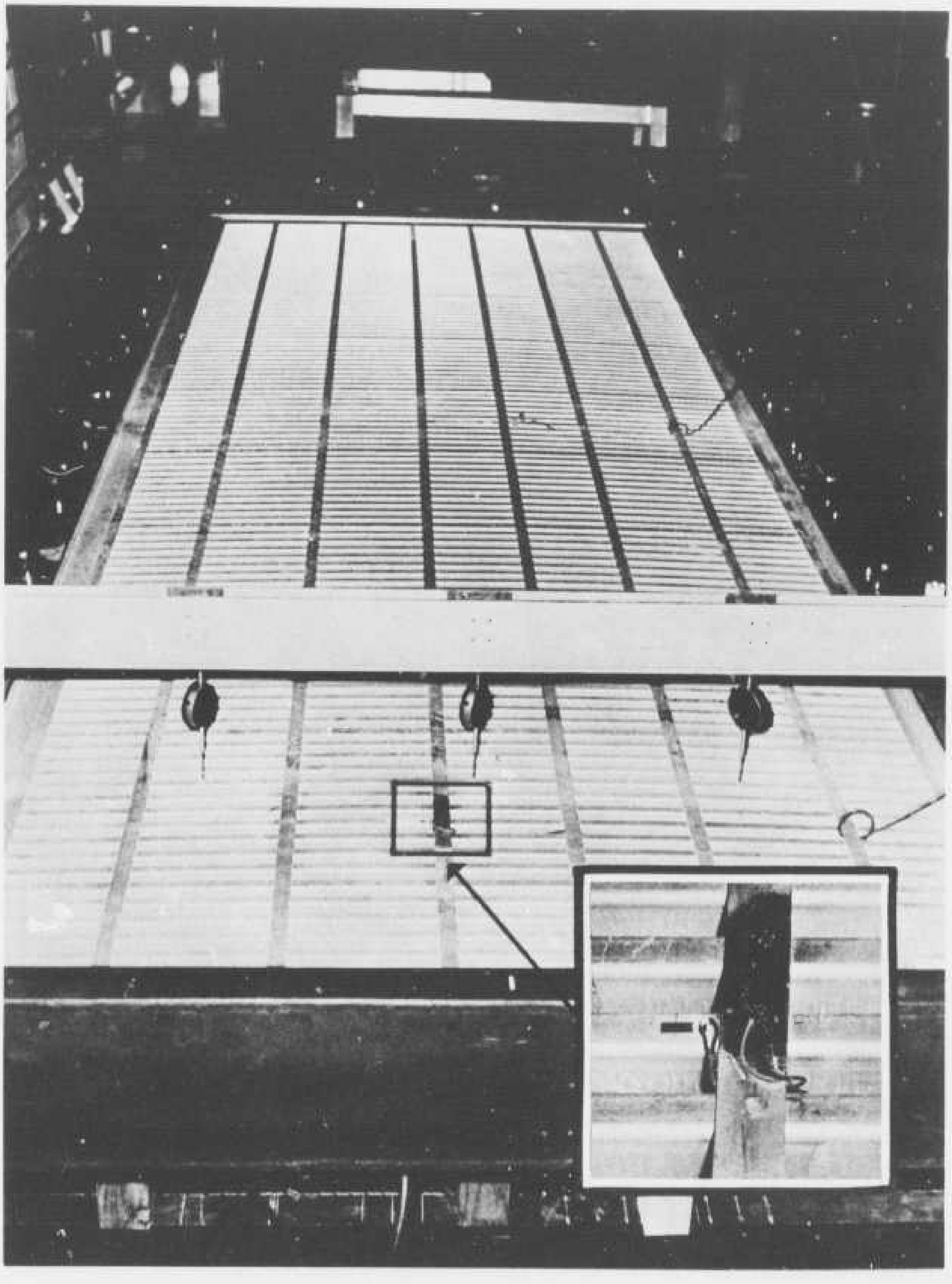


FIGURE 6 STRAIN GAGE APPLICATION DEFLECTION GAGES ON BRIDGE

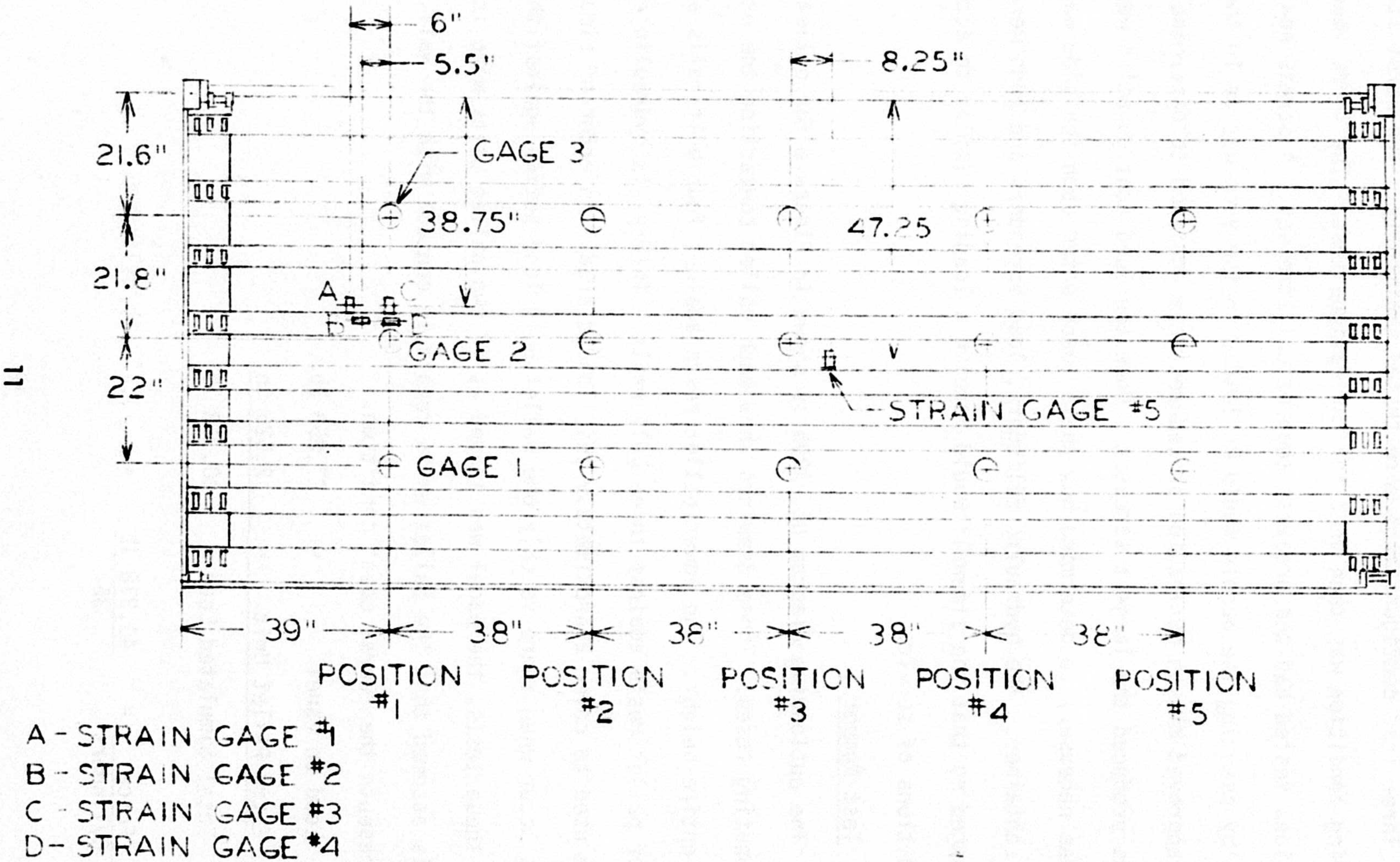


FIGURE 7 POSITION OF STRAIN GAGES AND MEASURED DEFLECTION POINTS

III TEST PROCEDURES

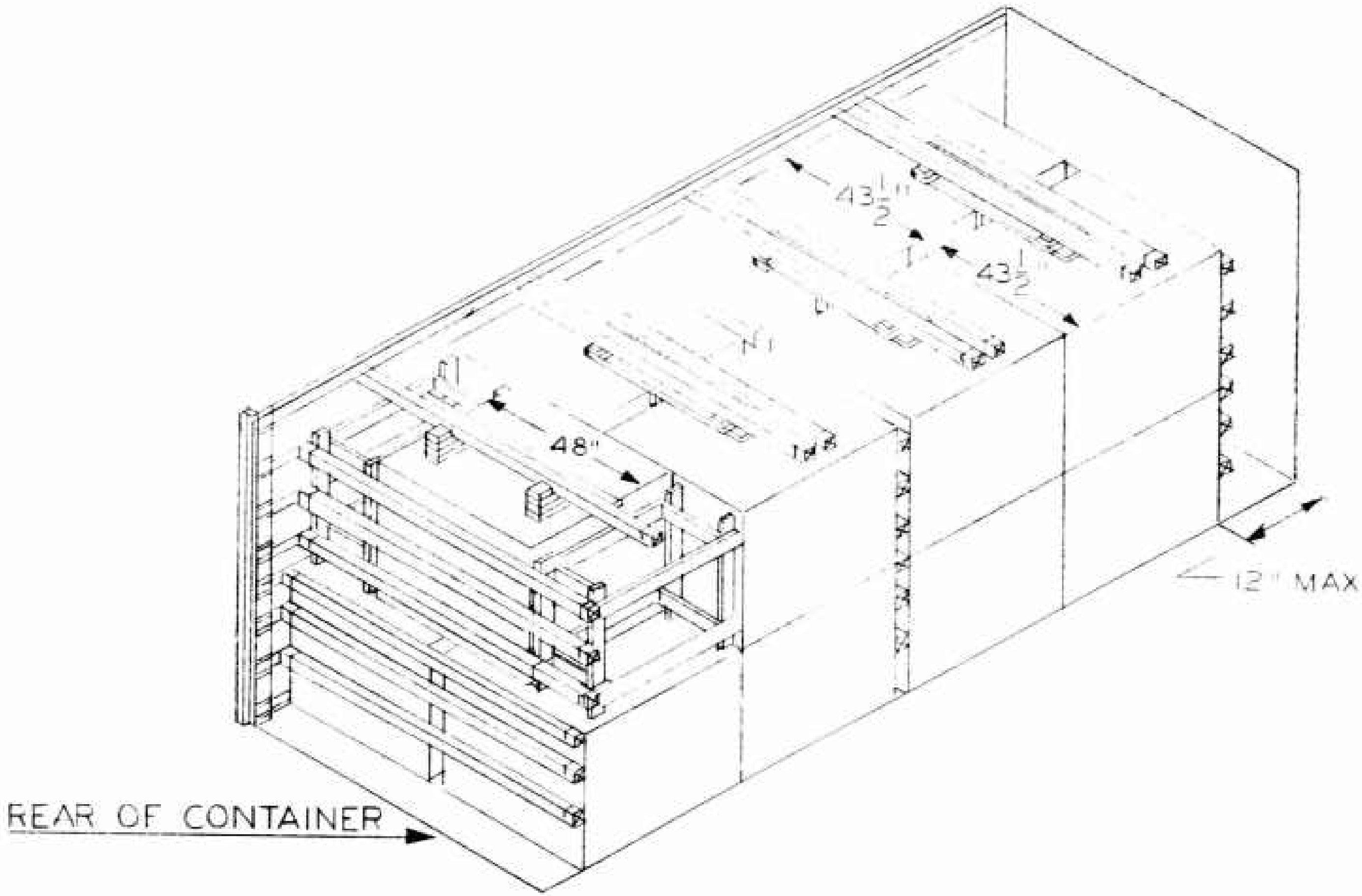
Three load configurations were tested statically. The worst static loading condition was then used for the fatigue test. The three load configurations tested had the greatest theoretical stresses. A stress analysis was made by assuming the panels would be loaded in the same way as in the Milvan. The approved Milvan outloading procedures were analyzed to determine which loads produced the largest stresses. Once the load configuration was chosen, it was necessary to determine how these loads acted upon the side walls of the container. The hydraulic cylinders, load spreaders and pads were then arranged so that the sidewall would receive a loading similar to actual conditions of service.

Test Number 1

The outloading diagram No. 4295 is shown in Figure 8 for palletized detonating fuses. These drawings show each pallet contacting the wall over its entire height. The lower pallet rests against four belt rails and the upper pallet rests against three belt rails. Thirty-six hydraulic cylinders were used to cover approximately this loaded area. An error of simulation does occur when there is only one pallet unit load acting against the wall. For these tests, the panel was loaded as if two pallet units were in place. It is assumed that the pallet units remain in contact with the wall. This represents the "worst case" condition.

Load On Panel	=	37,853 lb
Extra Pallet Unit	=	2,525 lb
Total Simulated Load	=	40,378 lb

$$\frac{\text{Force}}{\text{No. Cylinders}} = \frac{40{,}378\ \text{lb}}{36} = 1{,}122\ \text{lb/cylinder}$$



DAMXSV - 4295

FIGURE 8

$$\text{Hydraulic Line Pressure} = \frac{\text{Force}}{\text{Cylinder Area}} = \frac{1{,}122\ \text{lb}}{1.77\text{in}^2} = 634\ \text{PSI}$$

The load spreaders and pads were arranged as shown in Figure 9.

Test Number 2

The outloading diagram No. 4275 is shown in Figure 10 for palletized eight inch projectiles. These pallet units bear against the walls at the base and top, which aligns with belt rails 1 and 4. The length of contact is about 205 inches. It is assumed that half the load acts at the top of the pallet and half at the base. Sixteen hydraulic cylinders were used to simulate this loading condition.

Load Weight On Panel = 38,481 lb

$$\text{Load Against Each Belt Rail} = \frac{38{,}481\ \text{lb}}{2\ \text{Belt Rails}} = 19{,}241\ \text{lb}$$

Load Length = 205.4 inches

Force/inch of length = 93.7 lb/in

Each hydraulic cylinder covers 23 inches width. The force developed by each cylinder is:

93.7 lb/in x 23 inches = 2,155.1 lb

$$\text{Line Pressure Needed is} = \frac{2{,}155.1\ \text{lb}}{1.77\text{in}^2} = 1{,}217.6\ \text{PSI}$$

The load spreaders and pads were arranged as shown in Figure 11.

Test Number 3

The outloading diagram No. 4251 is shown in Figure 12 for palletized 155mm separate loading projectiles. The pallet units bear against the walls at the base and top, which is in alignment with belt rails 1 and 3. In one area the projectiles are stacked two high and belt rails 4 and 6 are also being loaded. Twenty hydraulic cylinders were used to simulate this load.

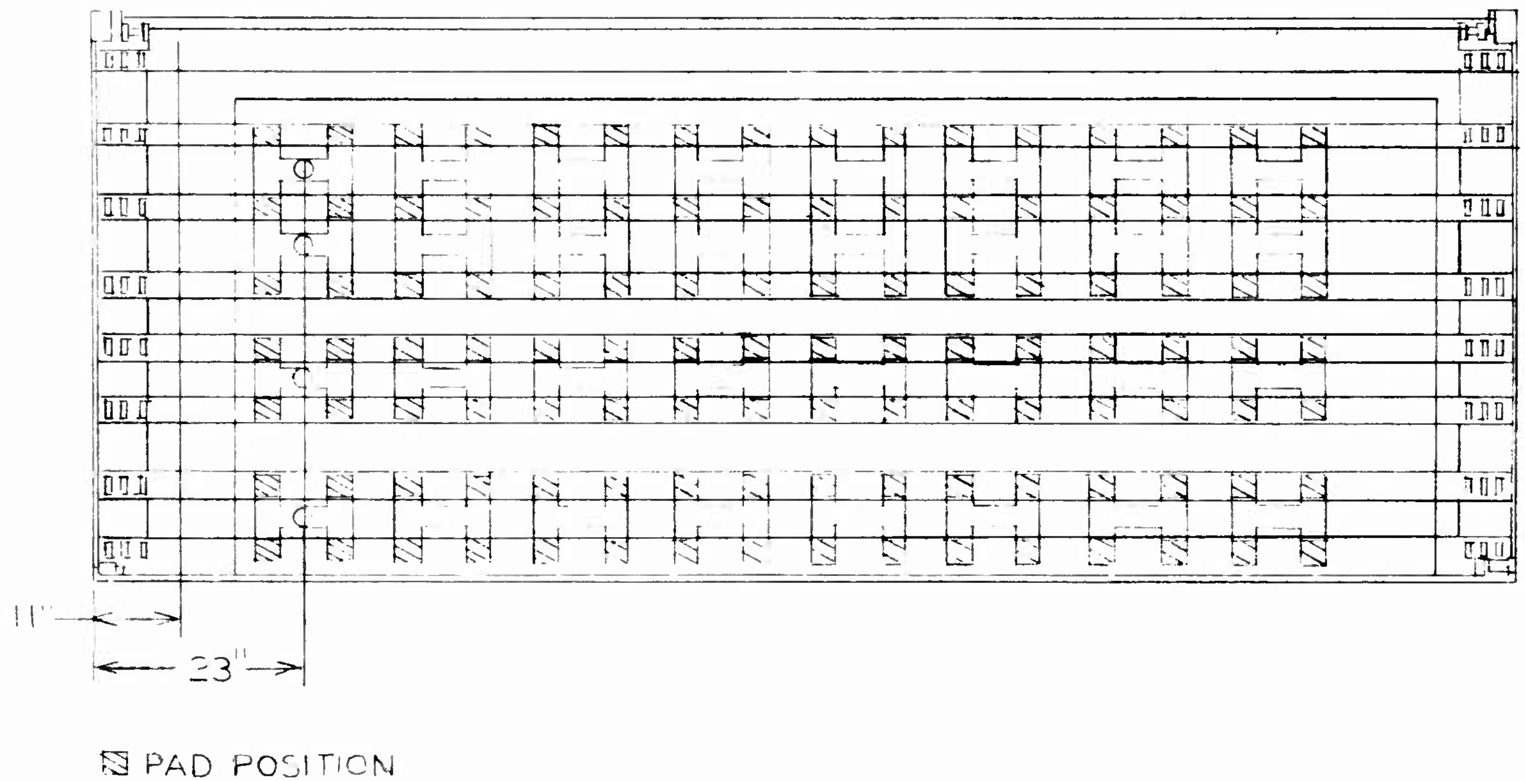
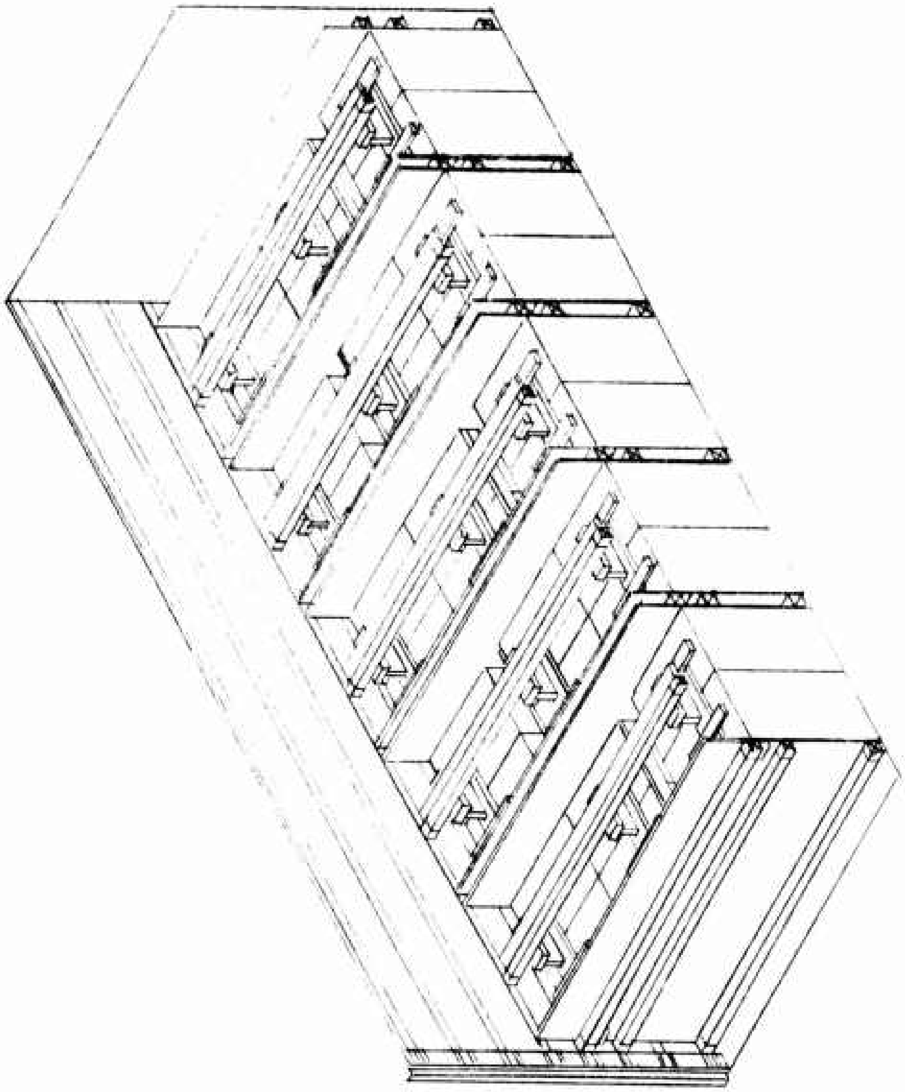


FIGURE 9 LOCATION OF JACKS & LOAD SPREADER PADS LOADING 4295 - FUSE



D - AMXSV - 4275

FIGURE 10

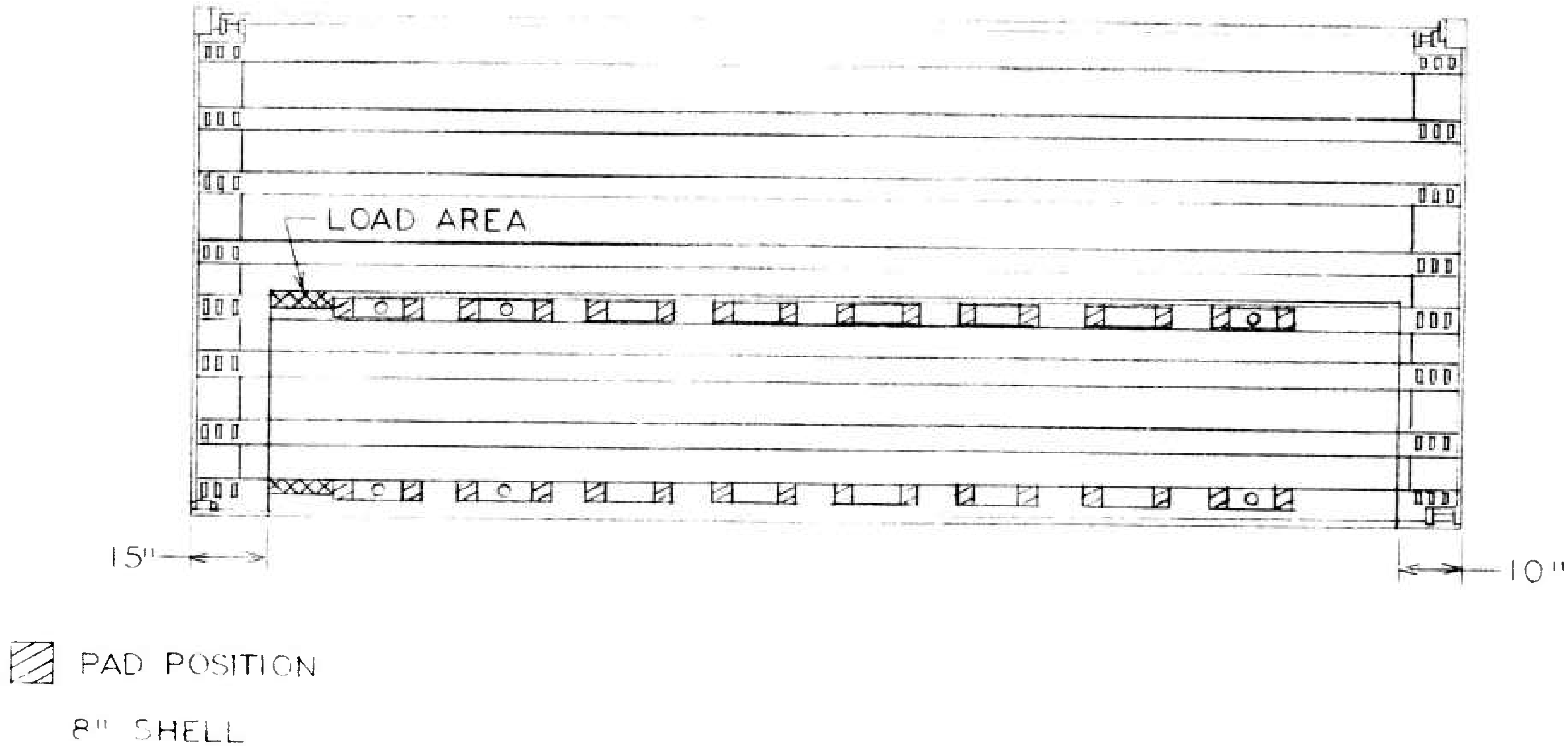
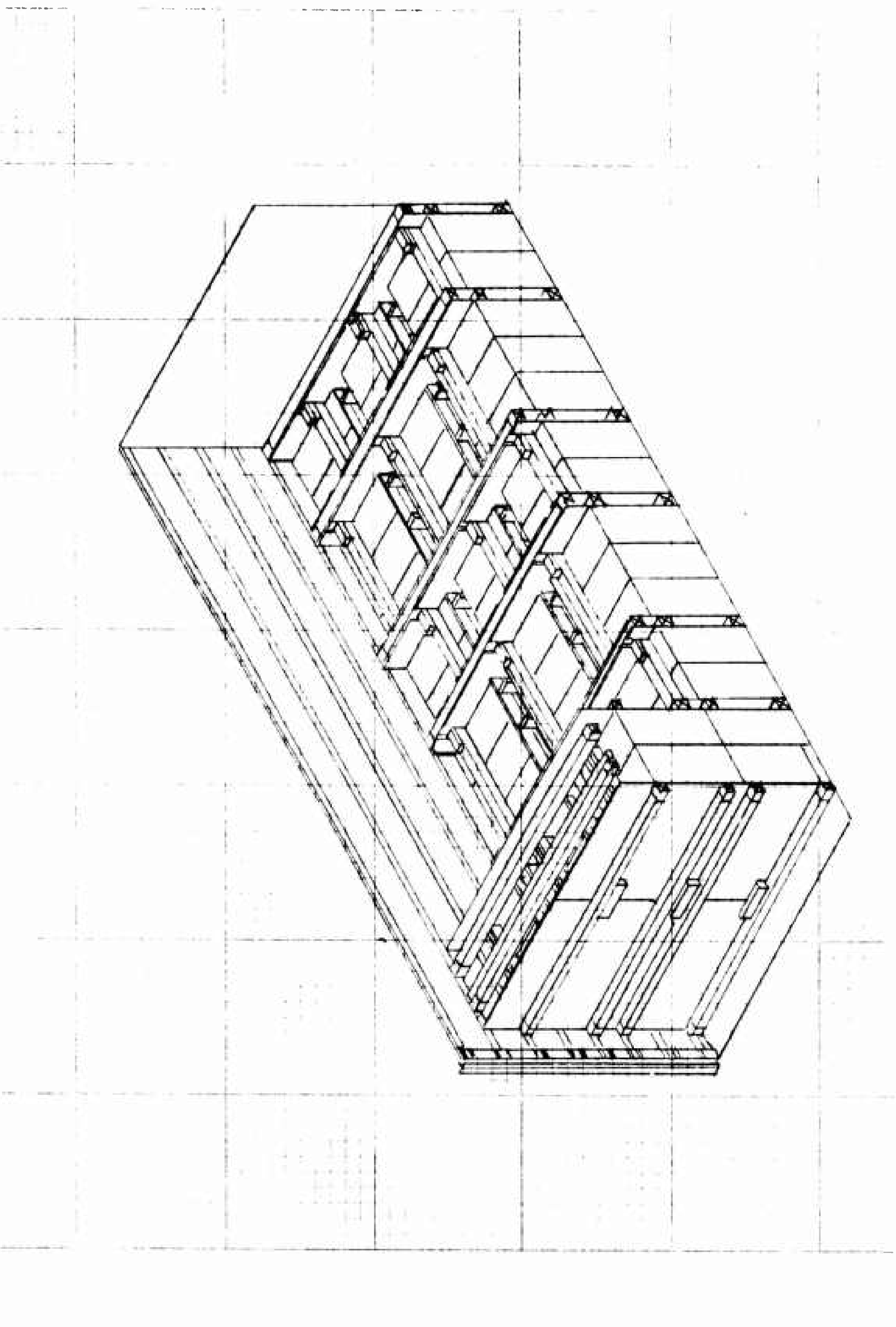


FIGURE 11 PATTERN 4275



D - AMXSV - 4251

FIGURE 12

The length of the wall that was loaded is 202 inches. Eighteen cylinders were used to simulate the loads bearing against belt rails 1 and 3. Two were used to simulate the load bearing against belt rails 4 and 6.

$$\text{Weight of the Lower Pallet Units} = 14 \text{ rows} \times 3 \frac{\text{pallet}}{\text{row}} \times 813 \frac{\text{lb}}{\text{pallet}} = 34{,}146 \text{ lb}$$

It is assumed that the load is evenly divided between belt rails.

The force acting through the belt rails of lower pallet units equals:

$$\frac{34{,}146 \text{ lb}}{2} = 17{,}073 \text{ lb}$$

$$\text{The force/unit length} = \frac{17{,}073 \text{ lb}}{202 \text{ in}} = 84.52 \text{ lb/inches of length}$$

Each cylinder covers a width of 23 inches. The force developed by each cylinder is:

$$84.52 \text{ lb/in} \times 23 \text{ inches} = 1{,}943.96 \text{ lb}$$

$$\text{The line pressure} = \frac{1{,}944 \text{ lb}}{1.77 \text{in}^2} = \text{approximately } 1{,}100 \text{ PSI.}$$

The load spreaders and pads were arranged as shown in Figure 13.

Test Number 4

This test used the load simulation for diagram No. 4251 as in Test 3, however, an FRP Type ISO container sidewall was mounted between the munition restraint panel and the test fixture frame. The FRP was cut to duplicate the container size and bolted in place as shown in Figure 14. The bolt pattern is a duplicate of an actual cargo container.

The FRP sidewall was used because its deflection is greater than any other type material used in cargo container walls. Other typical materials used are steel and aluminum. The bolts used to fasten the panel into the fixture were the same size as the rivets that are actually used in the container sidewall.

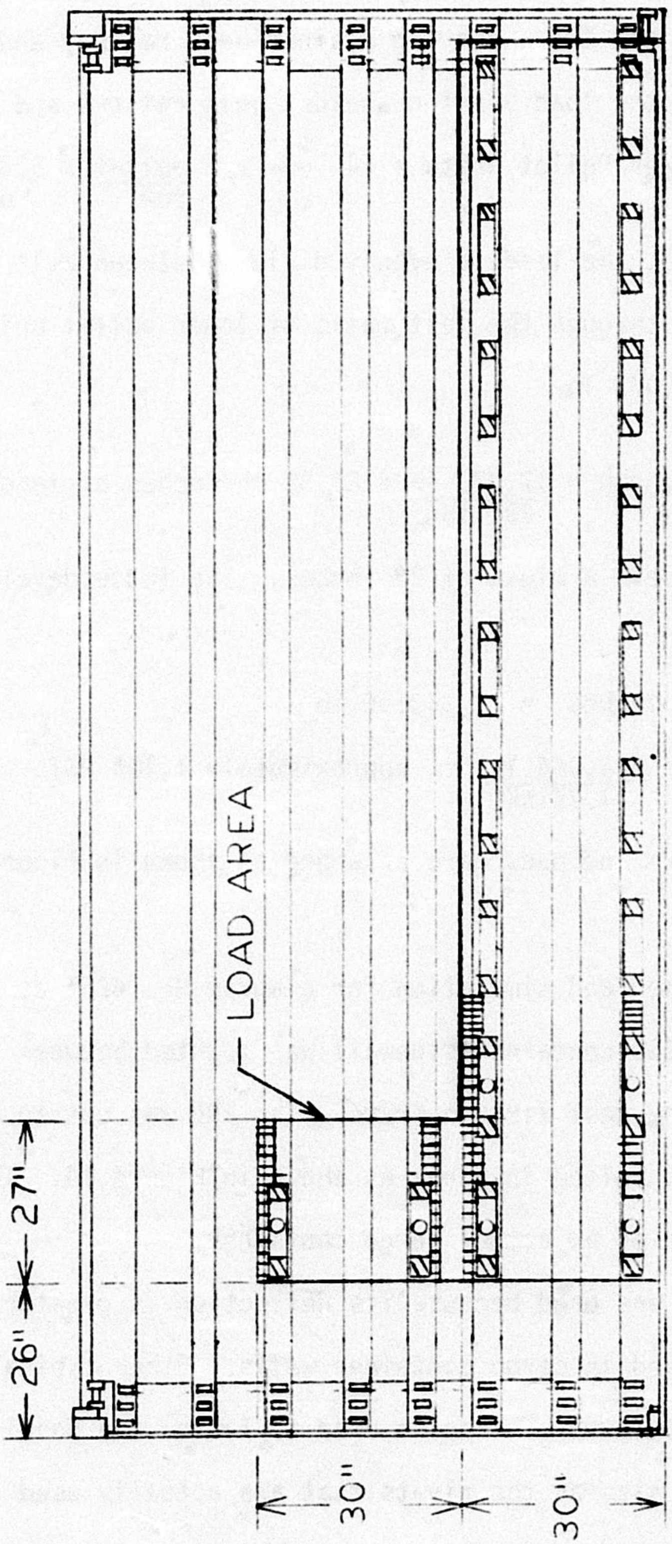


FIGURE 13 LOAD PATTERN 4251

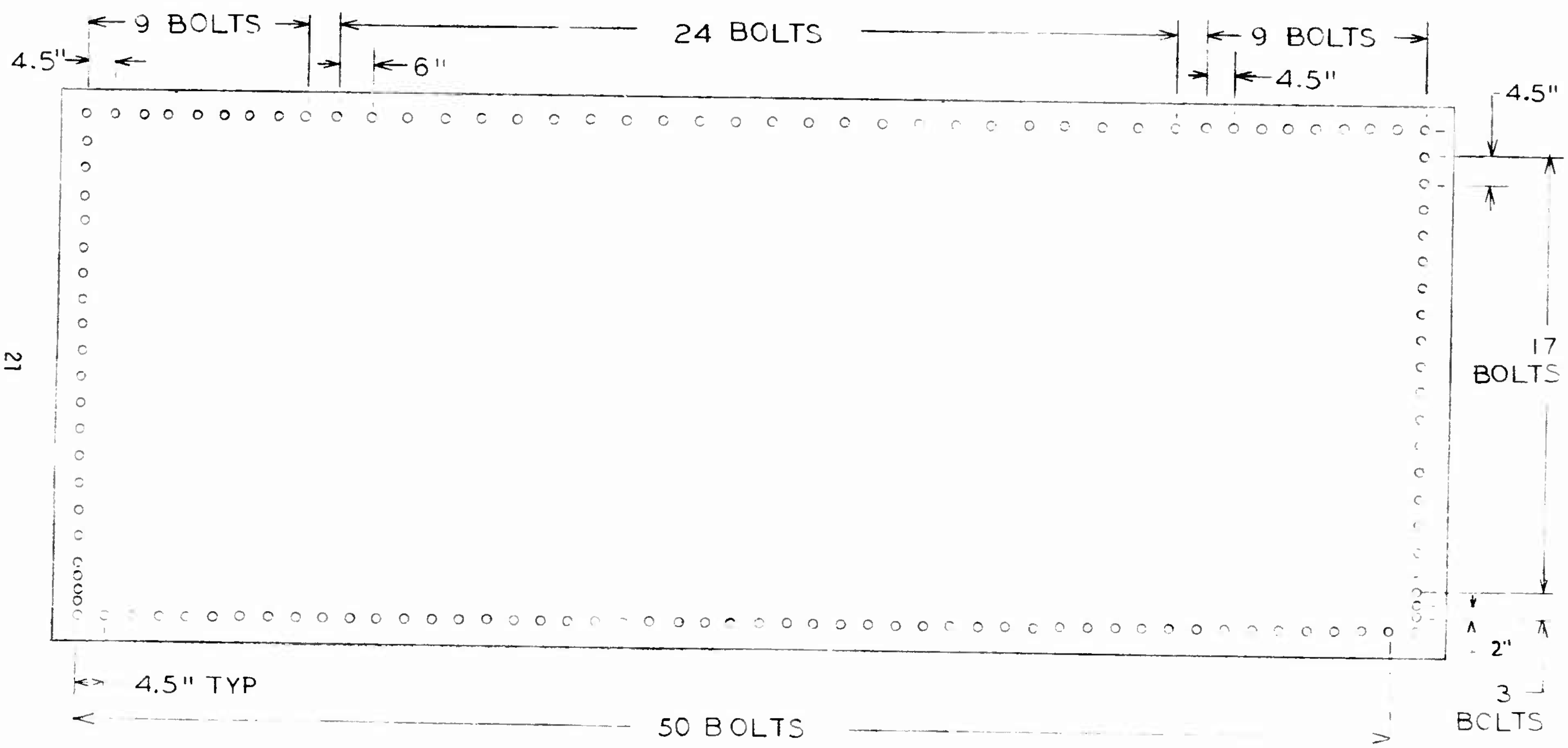


FIGURE 14 BOLT PATTERN USED ON F.R.P. CONTAINER WALL

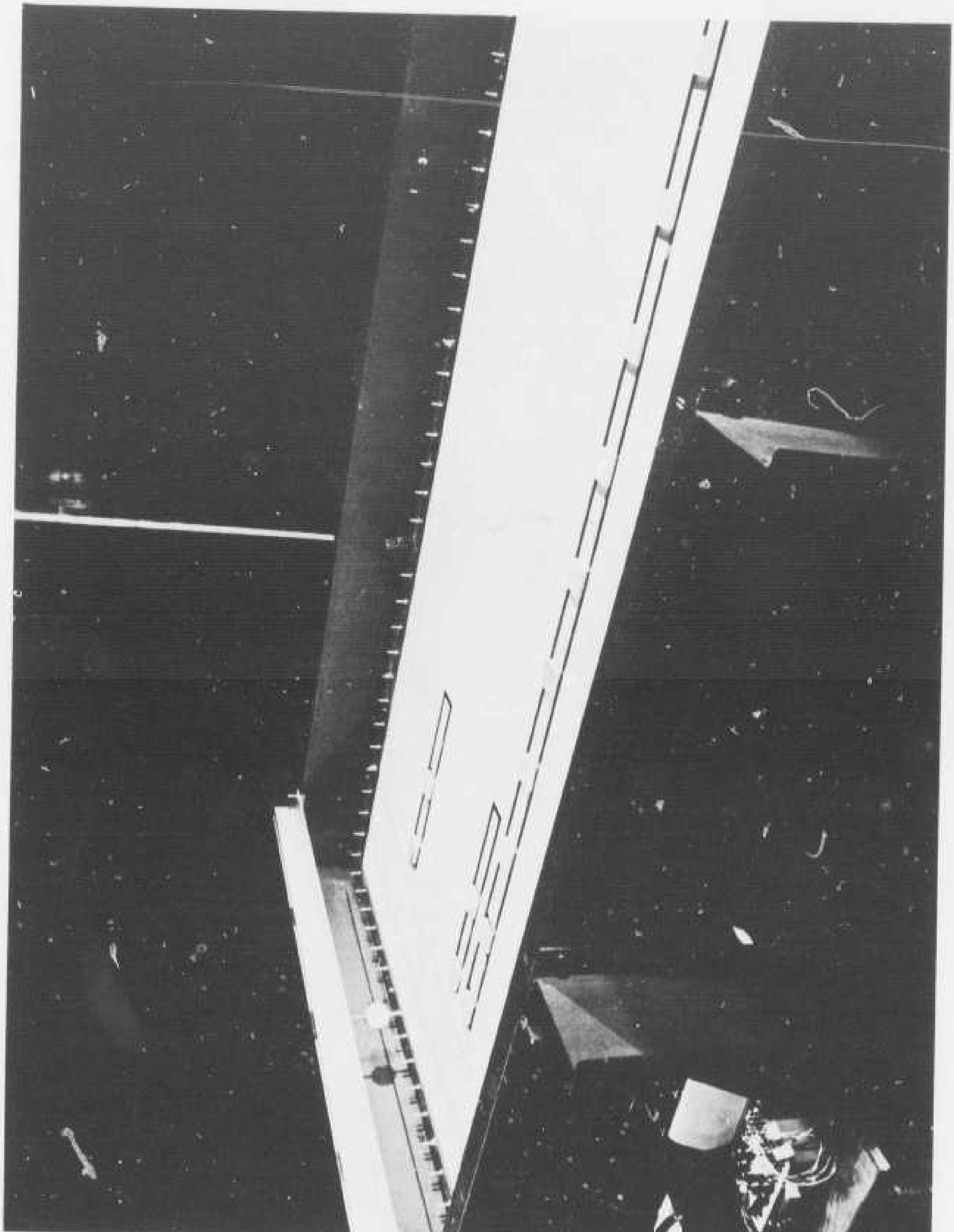


FIGURE 15 DYNAMIC TEST SETUP SHOWING POSITION OF LOAD PADS AND ACTUAL LOAD

The material fatigue test simulates the maximum dynamic forces acting on a container sidewall during ship's motion. *Based upon the worst possible assumption that could be made of a ship rolling three days in Sea State 10 conditions, the material developer (USAMERADCOM) specified an alternating force of 1 "g" ON/OFF. The loading cycle was approximated at 17 seconds, allowing 4 seconds to load the sidewall panel, 4 seconds to unload and 9 seconds at rest. The actual load application was sinusoidal but a natural log curve was traced.

IV TEST RESULTS

Test Number 1

The load pattern weight to be simulated was 37,850 pounds. The load actually applied was 40,400 pounds with the line pressure at 634 PSI. The strain gage at position No. 5 measured a maximum stress of 28,000 PSI, which is below the material yield strength of 35,000 PSI. It was noted that there are considerable end effects. However, at the center strain gage location, this effect is negligible and the panel acts as a beam. The maximum deflection was measured at 2.13 inches. The deflection and stress versus applied load curves are as shown on the graphs, Figures 16 - 25.

Test Number 2

The load pattern weight to be simulated was 38,480 pounds. The load actually applied was 34,480 pounds with the line pressure at 1,220 PSI. The strain gage at position No. 5 measured a maximum stress of 32,700 PSI, as shown in the graph in Figure 21. The center of the panel had the largest deflection (2.04 inches) and was acting like a beam with minor end effects from the panel

*The cyclic load for rolling was based on information obtained from marine architecture handbook data available at that time.

end restraint. As in the first test, the deflection curve had a flat, constant deflection section at the center. The difference between the actual and the simulated load is at the end of the panel's loaded areas where the hydraulic cylinders are not applied. It accounts for the 4,000 pounds difference in applied and actual loads. Because it does not affect maximum stress or deflection, it is of minor consequence.

Test Number 3

The load pattern weight to be simulated was 39,000 pounds. The load actually applied was 39,200 pounds with the line pressure at 1,100 PSI. The stresses developed at strain gage positions 1, 2, and 5, were 28,400, 34,700, and 17,300 PSI, respectively. The maximum stress was found in the panel tension strip where the pallets are stacked two high. This indicates that the tension strips contribute to the strength of the panel. The deflection at this position (No. 2) was measured at 2.0 inches. During the above test, dial indicator No. 3 broke and no additional data was recorded from it.

Test Number 4

The fatigue test used the same simulation as Test Number 3 and had the load cycled between 0 and a maximum of 39,200 pounds. The test ran for 14,400 cycles to simulate a three-day storm. A continuous test (unattended at night) was started, but had to be halted when thirteen of the test fixture's bolts sheared. High strength bolts replaced the failed ones and the test was then run only during duty hours so that the test could be more closely monitored. The stresses, recorded by the strain gages, and the deflection remained unchanged during the entire test. The maximum stress of 21,600 PSI was recorded by strain gage No. 2.

Rivet failures occurred at both the top and the bottom of the panel,

where the corrugation attached to the extruded frame sections. Ten rivets failed above the double pallet load. (Figure 26). On the bottom, 64 of the 109 rivets failed. The rivets that failed are on the outside (FRP side) of the restraint panel. Although a large number of rivets failed, the panel did not come apart, since it was still held together by rivets on the opposite side.

The failed rivets were examined by the RADC Reliability Laboratory to determine the mode of failure. A closeup of rivet failure is shown in Figure 27. Examination revealed that rivets failed in tension rather than in shear. It is felt that this happened because the extrusion was held rigid. The corrugation pivoted at the edge of the extrusion, when a load was applied, causing the rivet to be placed in tension.

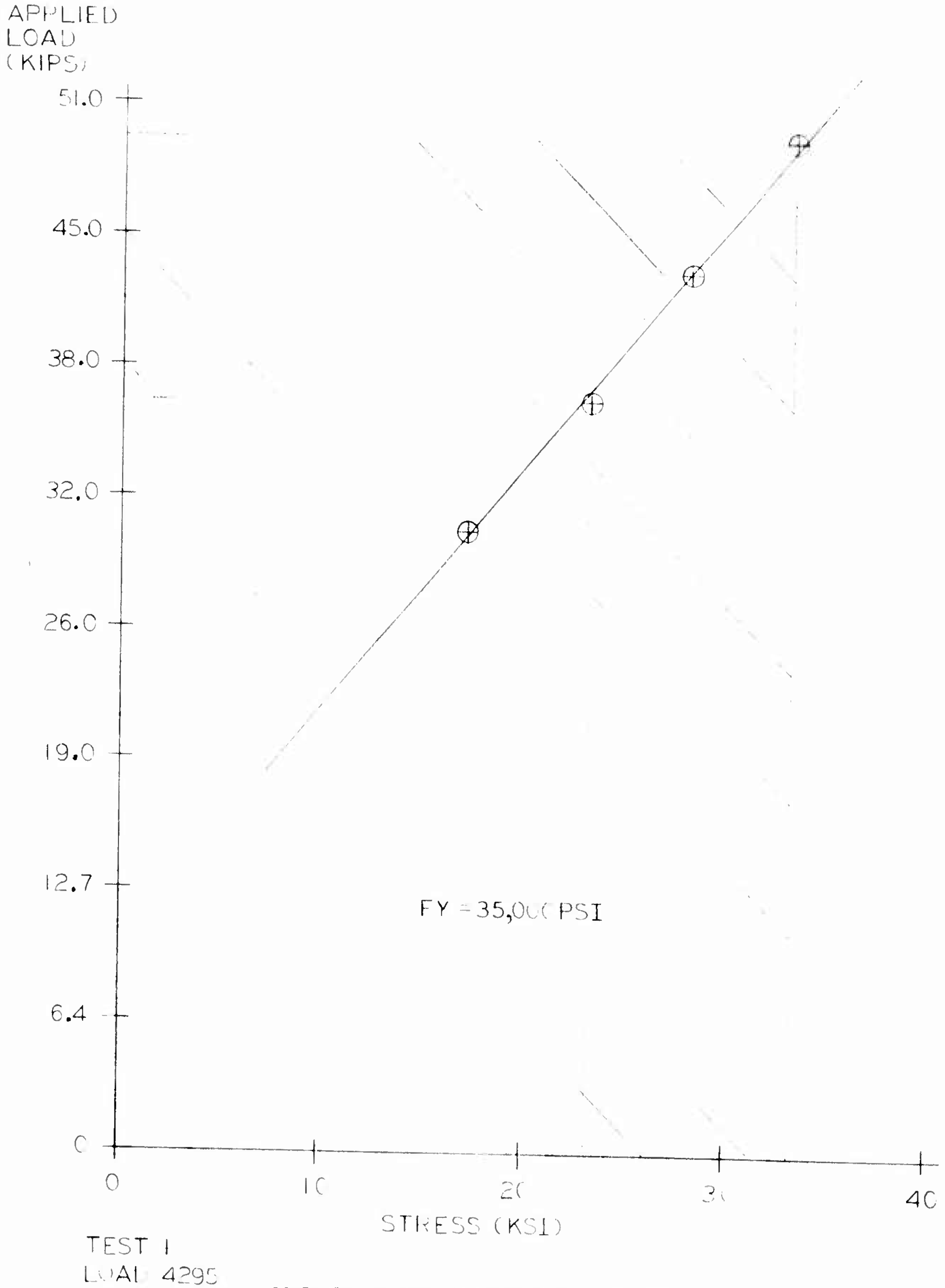


FIGURE 16 STRESS AT GAGE 5 VRS APPLIED LOAD

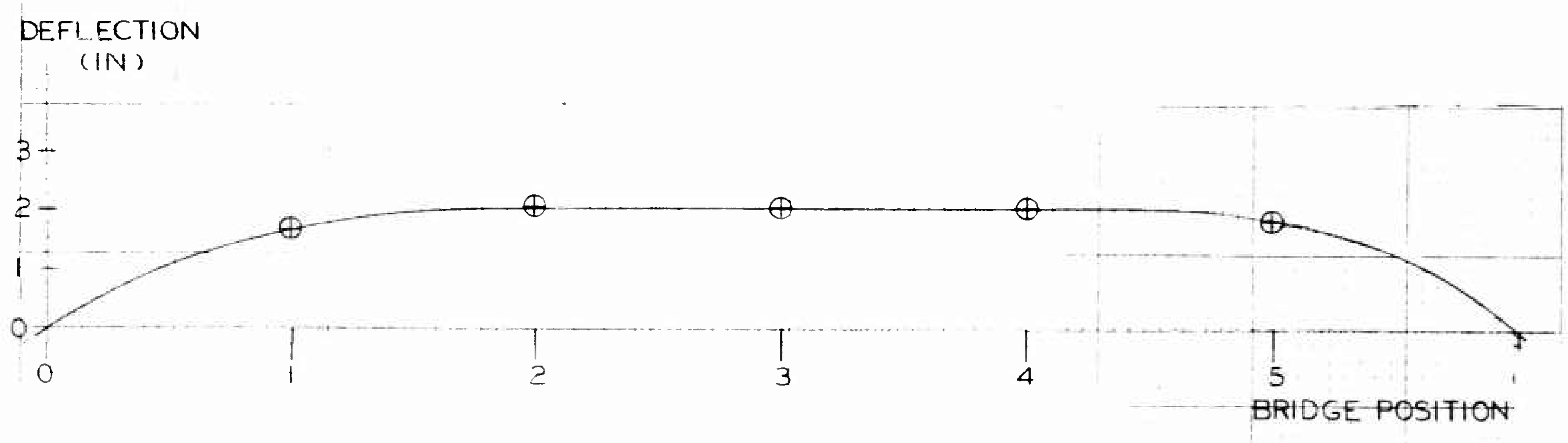


FIGURE 17 DEFLECTION ALONG LENGTH (AT GAGE 2)

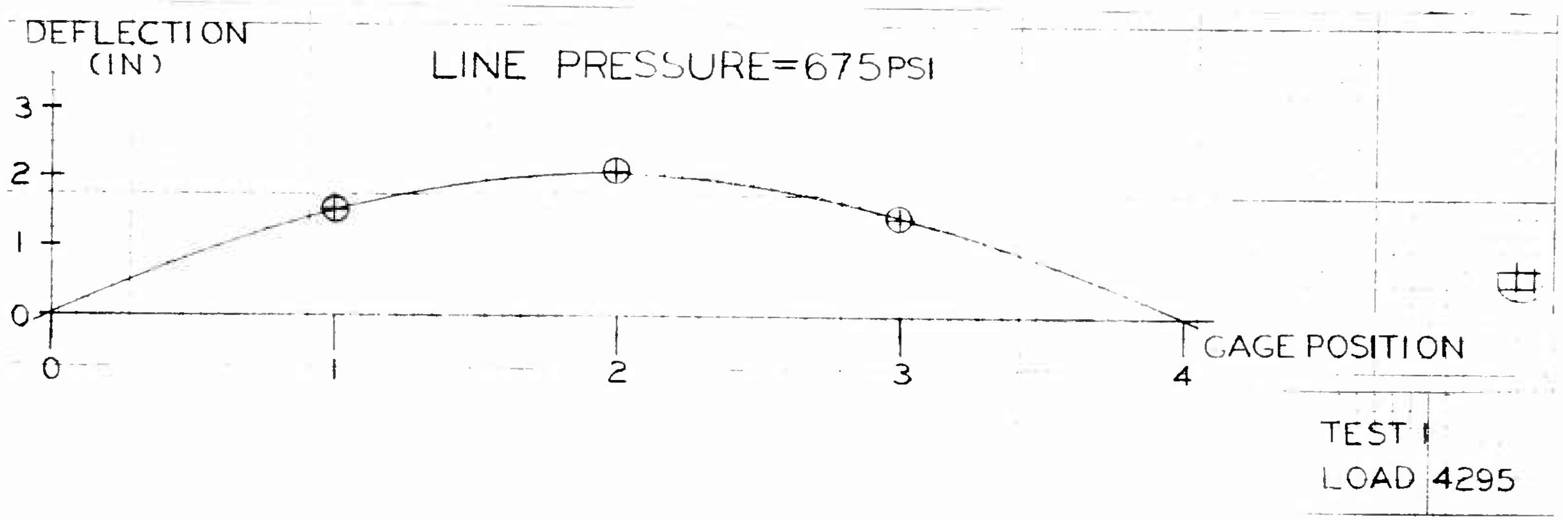


FIGURE 18 DEFLECTION ALONG HEIGHT (AT POSITION 3)

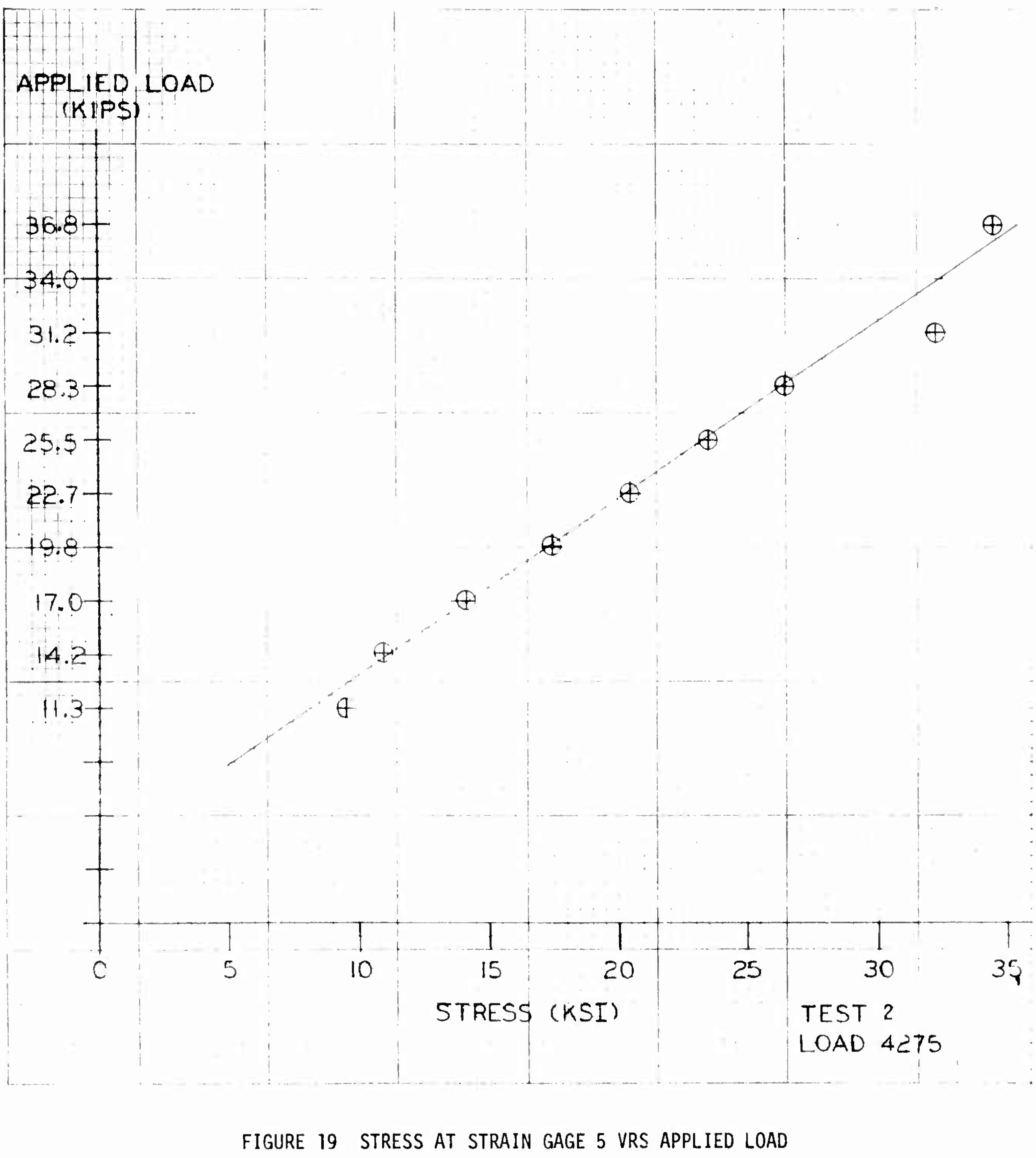


FIGURE 19 STRESS AT STRAIN GAGE 5 VRS APPLIED LOAD

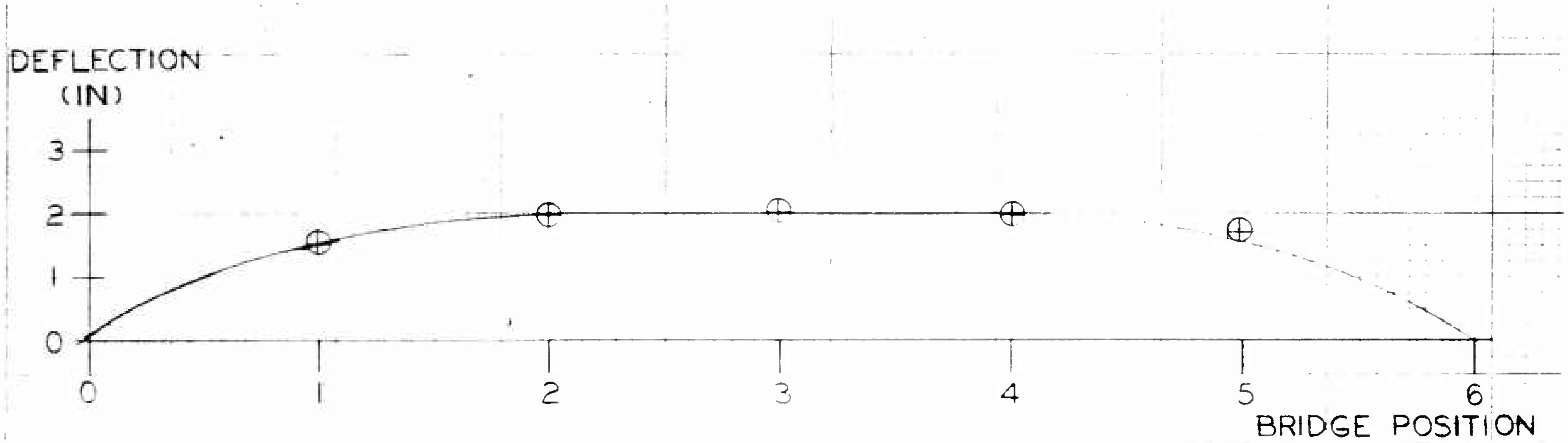
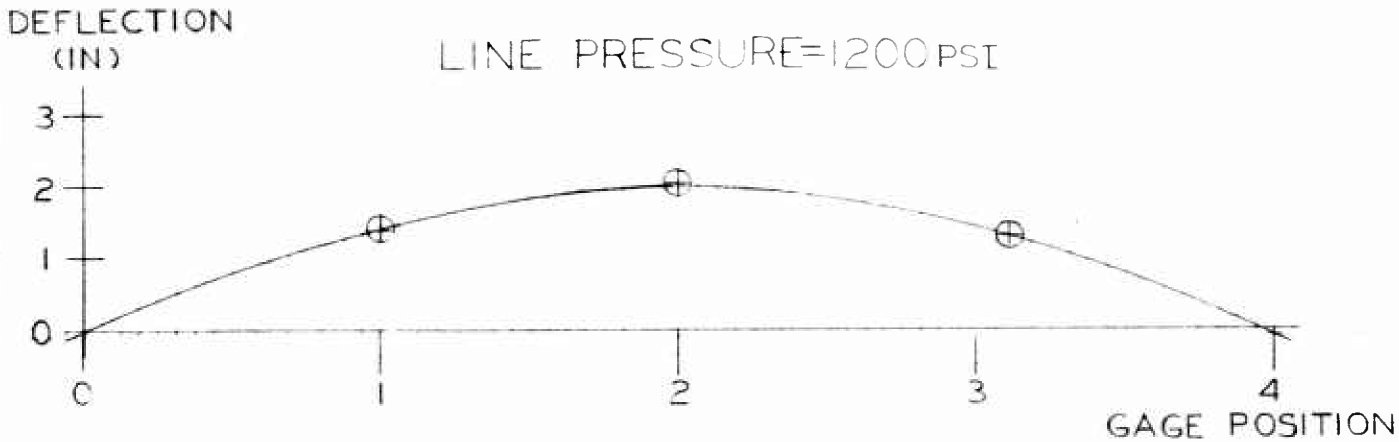


FIGURE 20 DEFLECTION ALONG LENGTH (AT GAGE 2)

LINE PRESSURE=1200 PSI



TEST 2
LOAD 4275

FIGURE 21 DEFLECTION ALONG HEIGHT (AT POSITION 3)

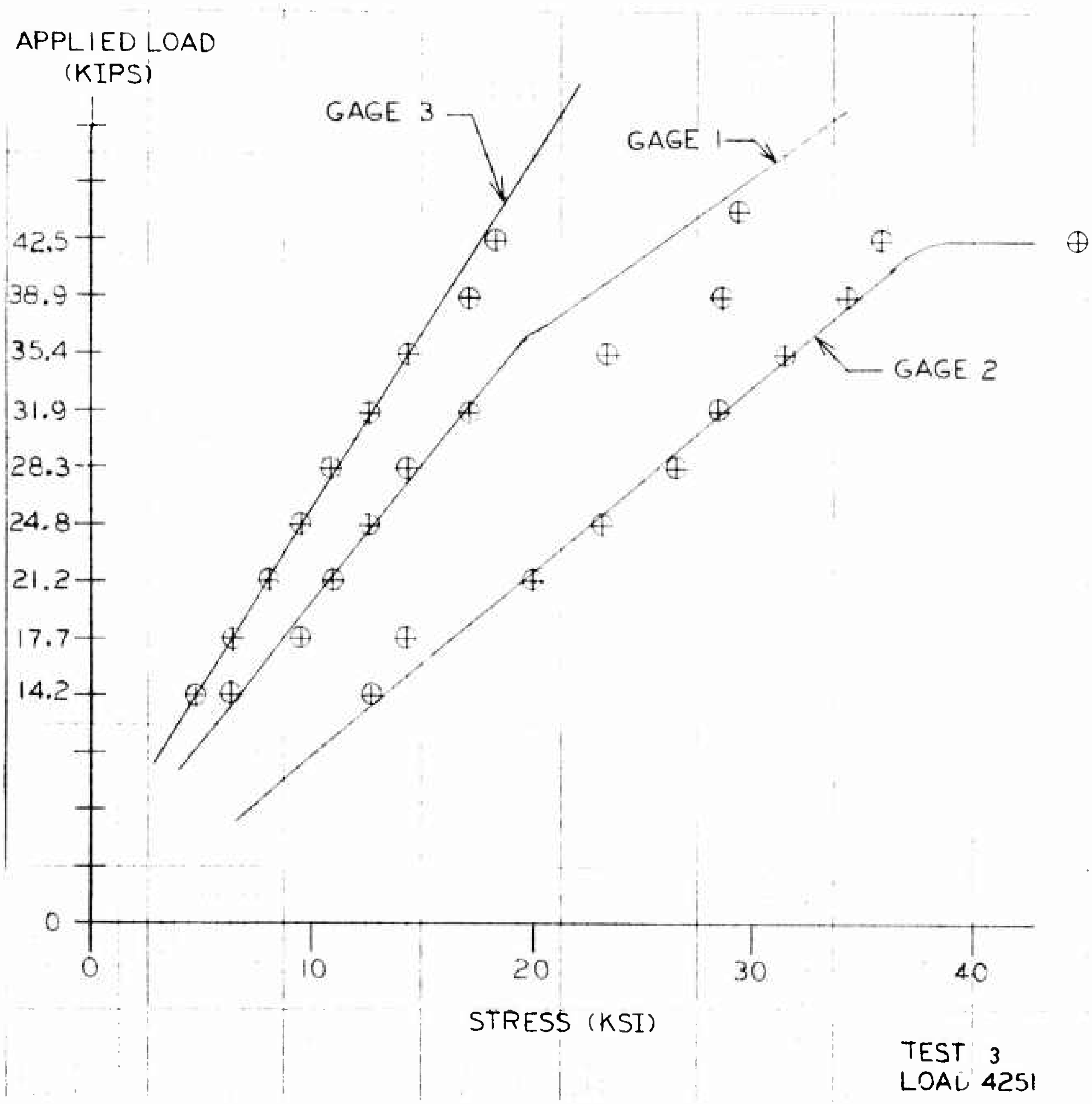


FIGURE 22 STRESS AT STRAIN GAGES VRS APPLIED LOAD

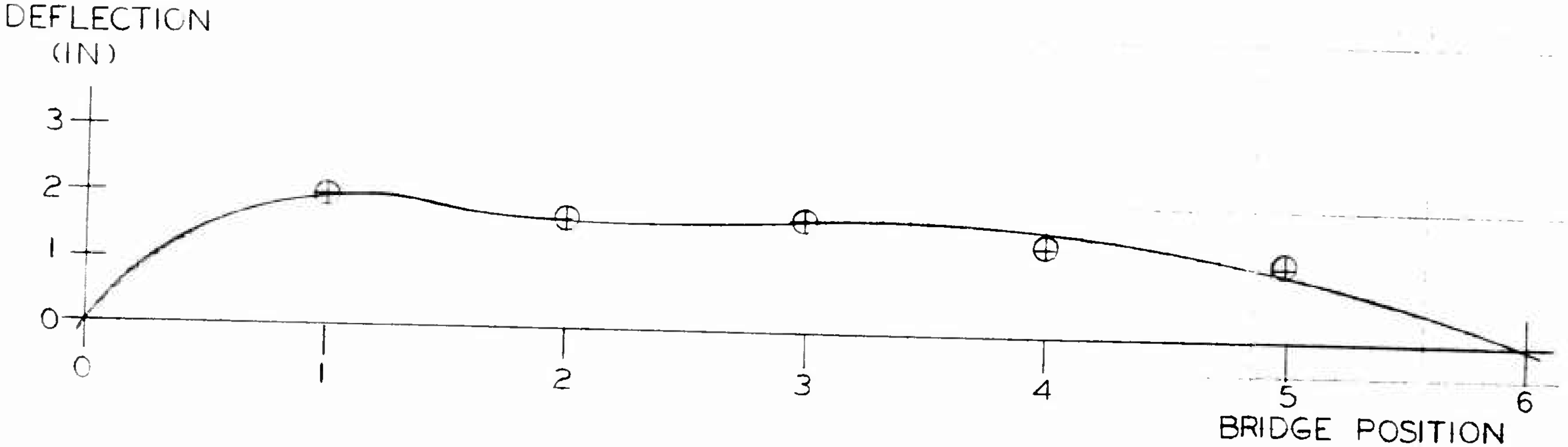


FIGURE 23 DEFLECTION ALONG LENGTH (AT GAGE 2)

LINE PRESSURE=1100 PSI

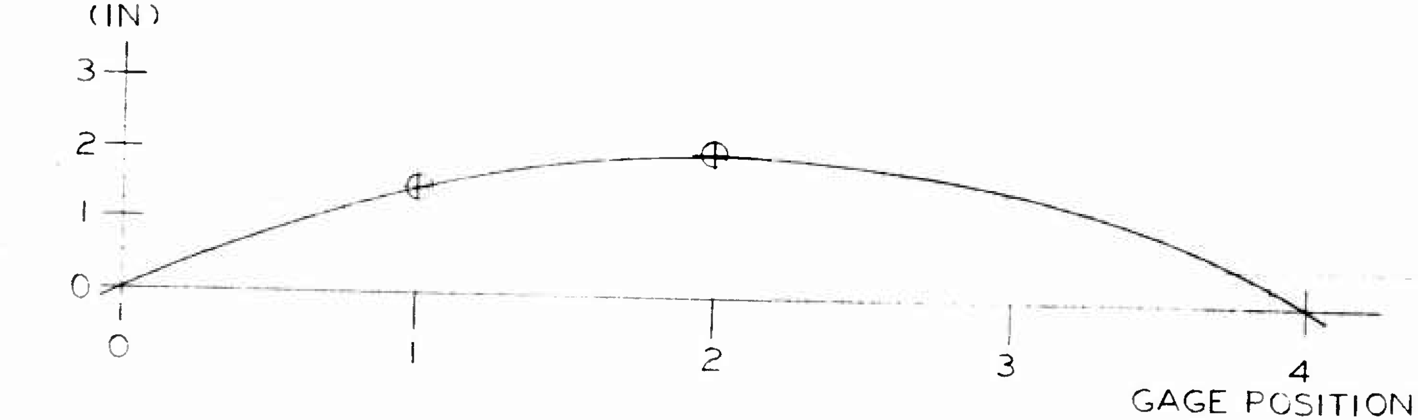


FIGURE 24 DEFLECTION ALONG HEIGHT (AT POSITION 1)

TEST 3
LOAD 4251

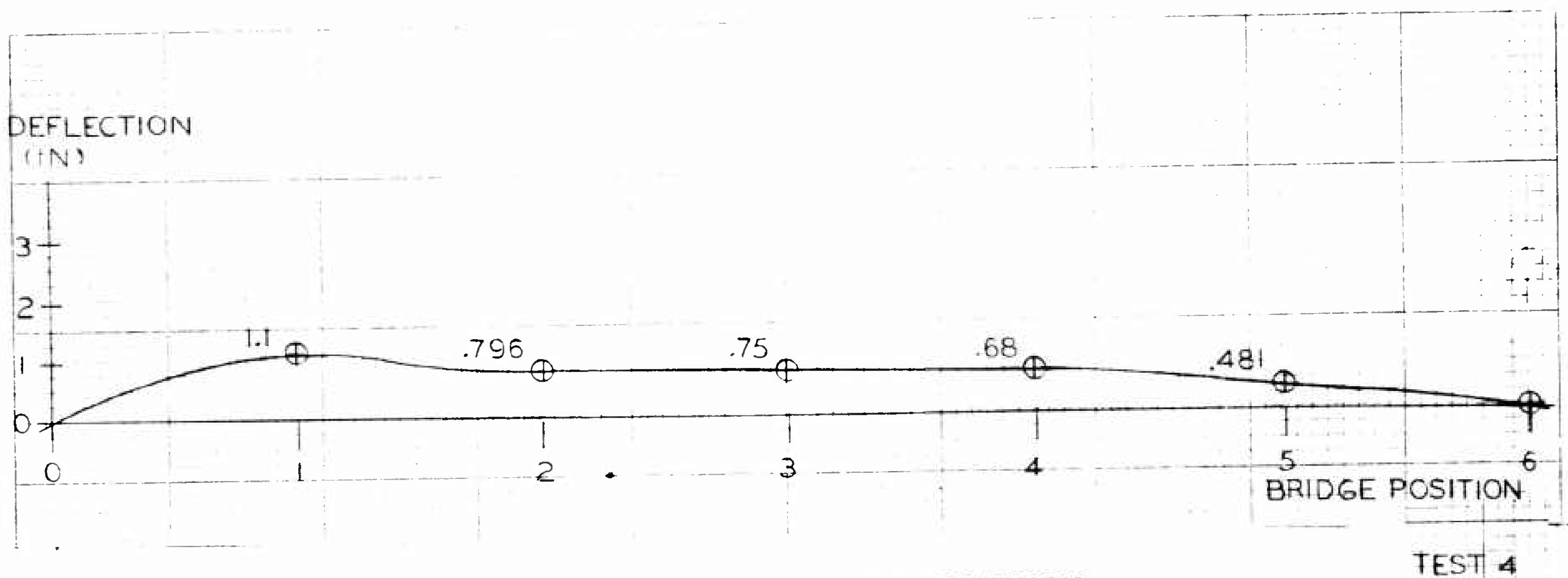


FIGURE 25 DEFLECTION ALONG LENGTH LINE PRESSURE 1100 PSI

STATIC DEFLEFTION AT CENTER LINE

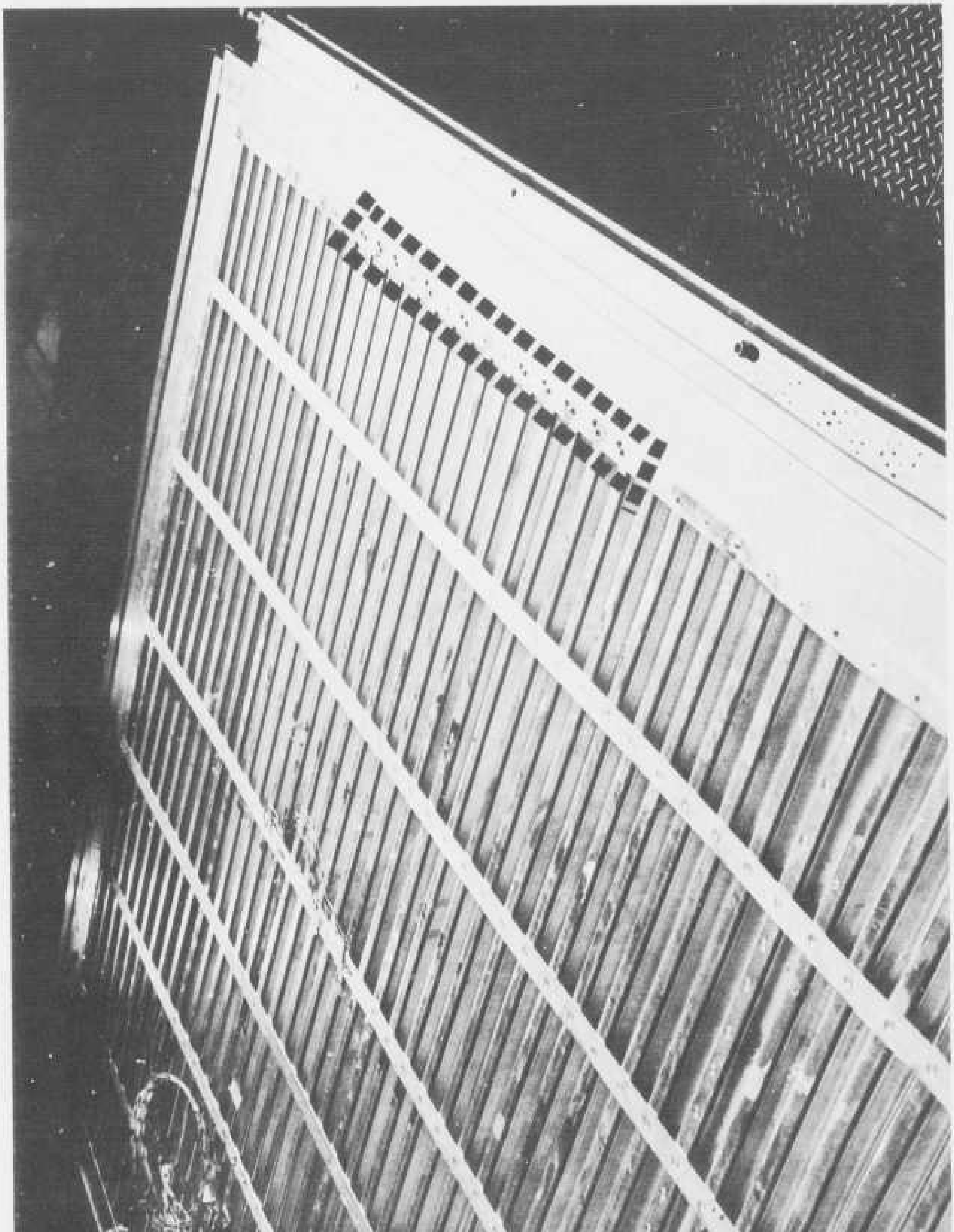


FIGURE 26 RIVET FAILURE

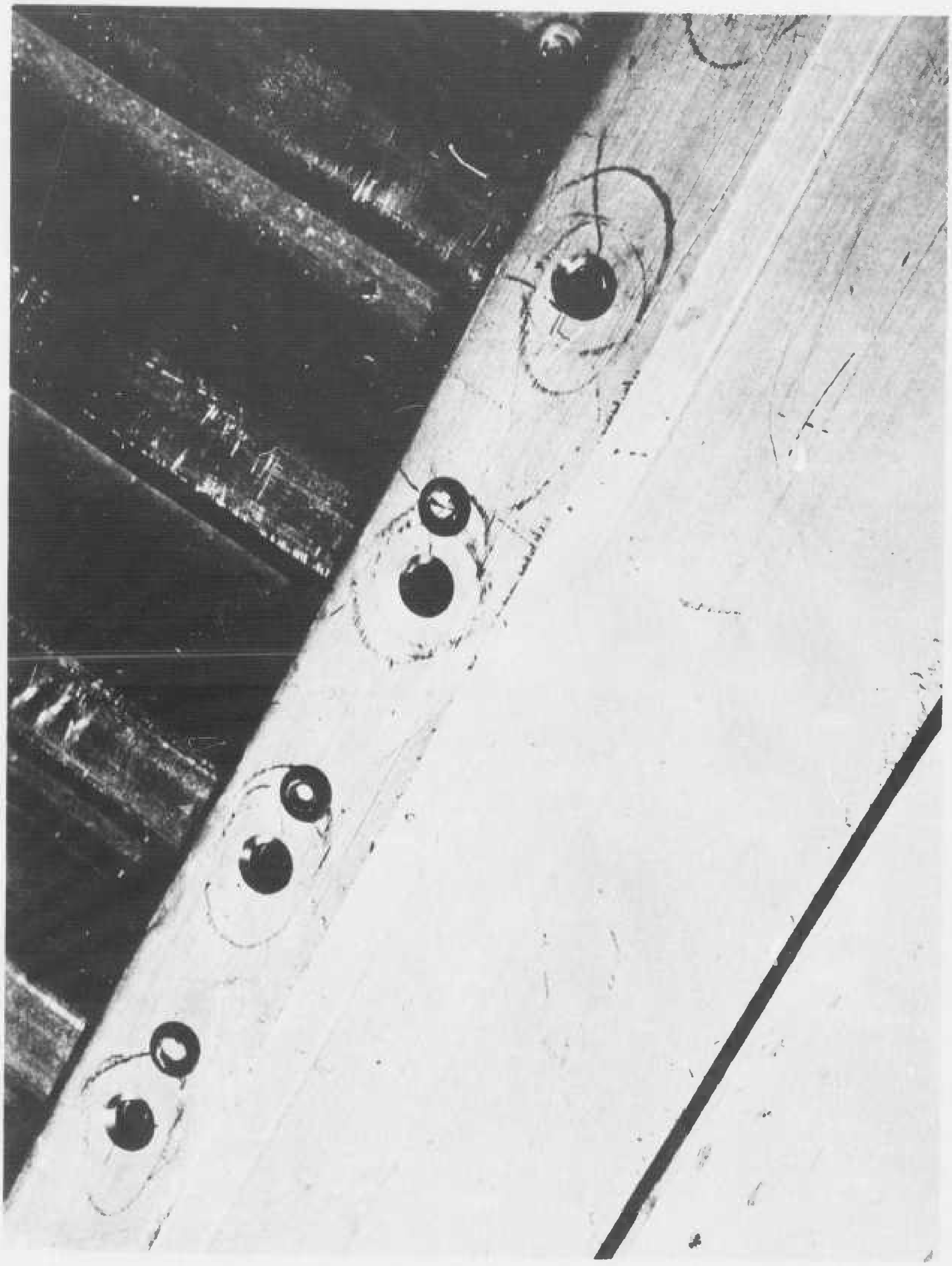


FIGURE 27 RIVET FAILURE CLOSEUP

TEST NUMBER	ACTUAL LOAD (LBS)	APPLIED LOAD (LBS)	MAXIMUM DEFLECTION	STRESS (PSI)	STRAIN GAGE NUMBER
1	37,850	40,400	2 in.	28,000	5
2	38,480	34,500	2 in.	32,700	5
3	39,000	38,900	2.2 in.	28,400	1
				34,700	2
				17,300	5
4	39,000	38,900	1.1 in.	12,000	1
				21,000	2
				12,000	3
				13,000	4
				9,000	5

FIGURE 28 TEST RESULTS SUMMARY

V SUMMARY

Panel skin stresses were found by using strain gages. A table of the data obtained from the strain gages is in Figure 28. The maximum allowable stress, from ASCE's "Specification for Structures of Aluminum Alloy 6061-T6", is 15,000 PSI. This maximum allowable stress was exceeded by stresses recorded from all the strain gages during the static tests. In the fatigue test, only stress from gage No. 2 exceeded the allowable. This stress was local since gage No. 4, which was very near, had a stress about half of gage No. 2. In the third test, gage No. 2 showed a stress very near the yield strength.

VI CONCLUSIONS

The tests have shown that the restraint panel has deficiencies that prevent it from safely supporting the static and dynamic loads. The deficiencies are shown by the rivet failures during the fatigue test and the high stresses recorded in the static tests.

The deflection pattern showed that the restraint panel was reacting both like a beam (supported on two sides) and like a true panel (supported on three sides) at different locations. The reactions are best shown by Tests No. 1 and 2 because of their symmetrical loadings. The center area, between measuring positions 2, 3, and 4, had an equal deflection, indicating that the panel was bending only in one plane. This is the same as a beam. Near the panel ends, between measuring positions 0, 1, 2, and 4, 5, 6, the restraint panel showed bending in two planes, similar to a true panel. This was caused by the third supporting side. The increased resistance to bending enabled this area to support a larger load than the center area. The double pallet load in Tests No. 3 and 4 were in this area and benefited from the added strength.

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